CRACKING IN THE METACARPO-PHALANGEAL JOINT

By J. B. ROSTON and R. WHEELER HAINES
St Thomas's Hospital Medical School

INTRODUCTION

Joint cracks have always aroused the interest both of anatomists and of casual observers, yet no detailed investigation of their nature appears to have been made. Nordheim (1938) and Mennell (1939) have made important contributions on the radiological and physical phenomena associated with cracks; their conclusions are considered later, after a description of the various phases of a typical cracking joint. Detailed observations and measurements have here been restricted to the metacarpo-phalangeal joint of the medius, but other joints have been used for comparison.

THE PHASES OF A TYPICAL CRACK

A tension of about 5 kg., insufficient to produce a crack, applied to the metacarpo-phalangeal joint while the muscles crossing the joint are relaxed, leads to a separation of the bones by about 0·5 mm., sometimes by as much as 2·0 mm. A slight groove appears over the joint, and a gap can be felt between the bones. When, after exerting such a tension to separate the articular surfaces, the bones are suddenly forced together, a sharp knocking can be felt, and in favourable cases heard, by both subject and observer. The separation can be repeated indefinitely without altering the state of the joint, and will be spoken of as the phase of preliminary separation as opposed to the phase of rest.

Stronger tension results in the production of the crack. The bones are seen and felt springing suddenly apart, separating by a further 1–3 mm.; the crack is heard as a sharp report, and the skin groove becomes more conspicuous.

When, after cracking, tension is relaxed, the articular surfaces again make contact and the skin groove disappears; but with moderate tension, considerably less than that required to produce the crack, the bones become widely separated and the skin groove deep. Further direct tension on the joint will not produce a second crack; the joint is in a refractory phase. Very strong tension, up to the limit the subject can bear, separates the joint surfaces a little farther, to a maximum of about 4 mm.

The refractory phase can be prolonged indefinitely by continuous or intermittent tension on the joint. If, however, the joint is undisturbed it regains its ability to crack in about 20 min., and the whole cycle can be repeated. In our experience the minimum time recorded between two cracks produced by direct tension was 17 min., and never more than 22 min. rest was required before a second crack could be produced.

RADIOGRAPHIC OBSERVATION

A radiograph of a typical joint in the resting phase (Pl. 1, fig. 1) shows the bones separated by a gap of 1·8 mm., the combined thickness of the articular layers of cartilage covering the two bones. Under moderate tension (Pl. 1, fig. 2) the bones lie a little farther apart, in the phase of preliminary separation, but the tissues between them still appear homogeneous since synovial fluid cannot be distinguished radiographically from the solid tissues that surround it. The separation of the bones in other joints has been recorded radiographically by Mennell (1939), and its occurrence negatives the possibility that cracking could be due to the breaking of a cohesive film between the articular surfaces, since they are already separated by a macroscopic interval before the crack is heard.

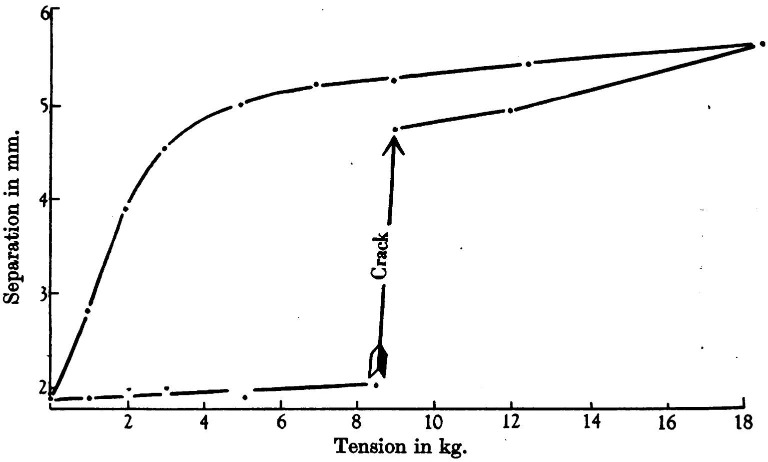
A radiograph taken under moderate tension immediately after cracking (Pl. 1, fig. 3), confirms the wide separation of the bones in this phase, and shows a sharply outlined clear space in the interior of the joint cavity. This space is bounded proximally and distally by the articular cartilages, whose surfaces can now be distinguished quite clearly in the radiograph, while, laterally, it bulges evenly outwards between the bones. Further tension leads to some enlargement of the space (Pl. 1, fig. 4), and alteration in its shape as it spreads over the articular surfaces, so that it eventually becomes ◠-shaped in antero-posterior view, the slightly curved chord of the D corresponding to the surface of the head of the metacarpal and the convex limb to the concavity of the base of the phalanx. The superimposed flexor and extensor tendons now make a vague shadow across the space. Exsanguination of the limb by winding a tight rubber bandage round it from finger tips to shoulder does not affect the crack.

The appearance of spaces in joints under manipulation was noted by Fick (1911) in the metacarpo-phalangeal joint, but he did not discuss their nature, and their appearance in the normal living joint was immediately denied by Christen (1911). Dittmar (1932*a*) found that, in children, forces applied by pads and straps above and below the knee could lead to a separation of one or other of the femoral condyles from the surface of the tibia, and that the surfaces of the corresponding fibrocartilage were then outlined by a clear space. He and Felsenreich (1935), who repeated his work, were primarily interested in the possibility of photographing fibrocartilages for clinical purposes without the necessity of injecting the cavity with air, and neither author associated the spaces with cracking.

It was left to Nordheim (1938) to contribute an exhaustive and lavishly illustrated study on the spaces. He showed that they could be produced by suitable manipulations in most joints of normal individuals, whereas the earlier workers had supposed that the required separation of the bones could occur, in the adult, only in joints of which the ligaments had been weakened by disease. He was the first to associate the spaces in the metacarpo-phalangeal joints with cracking, a point we can confirm, since we have always been able to demonstrate a space after a crack.

After the production of a crack, spaces can be seen when relatively low tensions are employed (Pl. 1, fig. 5), and the ease with which the bones can be separated in the refractory phase may be ascribed to the presence of these spaces. When no tension is applied in the refractory phase, and the articular cartilages are allowed to fall into contact, no spaces are visible (Pl. 1, fig. 6).

Occasionally multiple spaces are seen after manipulations involving repeated traction and relaxation (Pl. 1, fig. 7).



Text-fig. 1. Record of the separation of the bones in a typical cracking joint (J. B. R.).

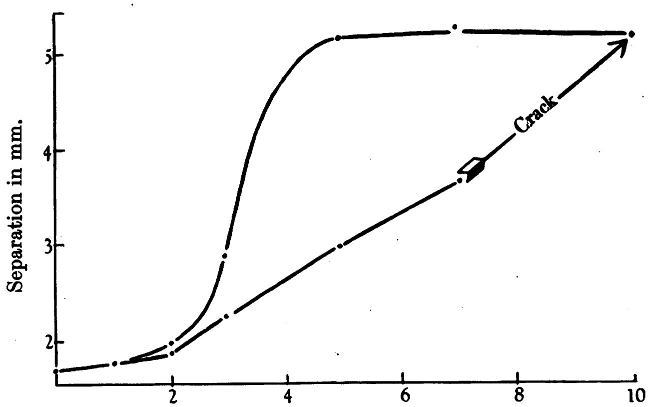
MEASUREMENT OF TENSION

For quantitative investigation the subject was seated near a radiographic table; his middle digit was wrapped with adhesive plaster, and a stout string was tied tightly over this, round the proximal phalanx. The string was then attached through a spring balance to the upright member of the travelling carriage supporting the radiographic tube. The subject was instructed to draw his hand away from the upright till the balance, acting as a tensiometer, recorded the desired degree of traction. The tendons of the subject's finger were palpated to make certain that the muscles were relaxed, and an exposure was made. From measurements obtained from such a series of records taken at different tensions, before and after cracking, graphs were constructed. The number of exposures available from a single individual was limited by considerations of safety to about fifteen.

In a typical instance (J. B. R., Text-fig. 1) the bones were separated in the resting phase by 1·8 mm., and tensions up to 8·5 kg. led to a separation of about 2·0 mm. At this tension the joint cracked, and the next radiograph, taken at 9 kg., showed a separation of 4·7 mm. A large space was now present and the thicknesses of the articular cartilages could be measured separately; each contributed 0·9 to the initial 1·8 mm. separation of the bones. Increase of tension to a maximum of 18·5 kg. led to a small increase in separation (5·6 mm. total).

The subsequent reduction of tension gave a graph of quite different shape, for the separation was still 5 mm. at 5 kg. tension whence it dropped smoothly to its starting point. The space was barely visible at 3·9 mm. separation and no longer detectable at 2·8 mm.

Other graphs of cracking joints showed variations in details, particularly in the degree of separation of the bones before cracking. In J. K., for instance, there was a separation of 3·7 mm. between the bones before cracking (Text-fig. 2). However, the curves have the same general form, a discontinuity always occurring at cracking and always associated with the appearance of a space.



Text-fig. 2. Record of the separation of the bones in a cracking joint showing wide preliminary separation (J. K.).

NATURE OF THE SPACES

Dittmar (1932*b*) suggested that, since he had introduced no air into the joints he had examined, the spaces observed could not be gaseous, but represented accumulations of synovial fluid which became visible in the radiographs, owing to the difference in specific gravity between the fluid and the neighbouring tissues. Felsenreich (1935) could not agree that this was possible. Nordheim (1938) investigated the point in the cadaver, and he found that a wrist joint subject to tension showed a space, but that the injection of water caused the space to disappear at once. He suggested accordingly that the space was a partial vacuum occupied by water vapour and gases under reduced pressure, and that the similarity between his preparations and those produced by the injection of air into joints was due to the similar radiographic properties of vacua and gas-filled cavities.

Nordheim compared the joint space to that which appeared in a hypodermic syringe half-filled with water when the entry was blocked and the plunger pulled back with sufficient force. Such partial vacua can be studied more conveniently in a van Slyke apparatus, and in either case the space appears when the pressure is reduced to the vapour pressure of water. In the joint, however, conditions are different, for the cross-sectional area of the fluid through which tensions are transmitted before cracking measures but 2 sq.cm. A tension of about 7 kg. is required to produce a crack, thus subjecting the fluid to a tension of $3\frac{1}{2}$ kg./sq.cm. Atmospheric pressure is about 1 kg./sq.cm., so that at the time the joint cracks the pressure in the cavity is minus $3\frac{1}{2}$ atm. on the relative scale ($-2\frac{1}{2}$ A. on the absolute scale).

The ability of columns of fluids such as water to withstand considerable longitudinal pulls without separation of their molecules, thus exhibiting an inherent tensile strength, is seldom seen in laboratory practice, for under ordinary conditions liquids boil as soon as the pressure within them falls to their vapour pressure. But when a fluid contains no unwetted dust particles, and is contained in a perfectly wetted vessel (conditions usually reached experimentally after temporary subjection to pressures of the order of 1000 atm., which drive all gas nuclei into solution), there are no foci left about which spaces can form. Water after such treatment can be heated to 200° C. without boiling and will support considerable tensions. Moreover, treated solutions of bicarbonates and acids can be mixed without frothing (Dean, 1944; Harvey, Whitely, McElroy, Pease & Barnes, 1944). Tall trees depend on this tensile strength of fluids, which is unaffected by dissolved gases, to draw up the sap, through the vessels, to the leaves (Dixon, 1938).

In animals the tensile strength of the body fluids has not been recognized as being of particular importance, but the presence of gas nuclei has been studied as they affect the appearance of bubbles after decompressions. They are absent from the interior of most cells, and unicellular organisms such as *Euglena*, *Paramoecium* and *Amoeba* do not develop bubbles in their protoplasm even after decompression from 100 atm. But bubbles form far more readily on the surfaces of the cells and are known to be responsible for the joint symptoms in caisson disease (Harvey, Barnes, McElroy, Whitely & Cooper, 1944). In man it is generally accepted that atmospheric pressure is of some importance in the prevention of sudden dislocations of joints, and now it may be added that the intrinsic tensile strength of the joint fluid, as it lies in the space whose walls it wets, may double or treble the passive cohesive strength resisting such dislocations.

Once a space has been formed in a liquid it can be expanded indefinitely by a traction sufficient to overcome atmospheric pressure, and Nordheim's (1938) comparison with conditions in a hypodermic syringe is now justified. Nordheim had no method of measuring the tensions he employed and did not realize the change of pressure in the interior of the joint as it cracked, from about

$-2\frac{1}{2}$ atm. to a little above the vapour pressure of water, a change which explains for the first time the sudden springing apart of the bones, and the setting up of vibrations in the tissues that are heard as the crack. Mennell (1939) ascribed the sound to the sudden tightening of the fibrous capsule about the joint and this may play a part; but he did not notice the spaces in his radiographs.

No explanation has been found in the literature of the inability to crack in the refractory phase. It may be suggested however that, when tension is relaxed after cracking, the large space contracts to a gas nucleus as does the space in the hypodermic syringe. Such a nucleus would be invisible in a radiograph, but on the renewal of tension would again expand, and would prevent the sudden decrease of pressure in a gas-free joint cavity, which is an essential preliminary to the production of the crack. The duration of the refractory phase after cracking would correspond to the time required for such a minute bubble to pass into solution. This suggestion conforms to the facts, though the difficulty of demonstrating the presence of this nucleus in the resting joint has not yet been overcome.

THE SYNOVIAL FLUID

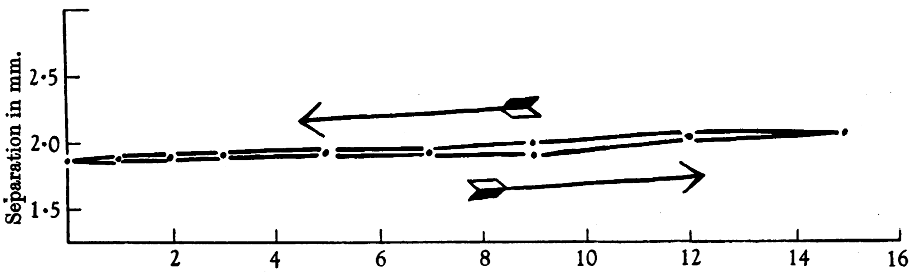
It is generally agreed that, apart from the mucin it contains, synovial fluid is a simple transudate, so that the pressure within the joint cavity should affect the rate of its formation. In the series of joints discussed in this paper, changes in the amount of fluid were kept at a minimum by maintaining tension across the joint for the shortest time compatible with achieving a steady tension and the making of the record.

Nordheim (1938), using continuous traction on the knee, found that after 2 min. the space was smaller and had broken up so as to appear like a string of pearls; after 10 min. no space remained, and the interior of the joint cavity appeared evenly dark in the radiograph, an effect he ascribed to a rapid inflow of synovial fluid obliterating the space. We have not been able to observe such massive inflows in the metacarpo-phalangeal joints, for after 10 min. continuous tension the space is still clear. Possibly the great extent of the synovial membrane of the knee, and its scantiness in the finger-joints, accounts for the differences observed.

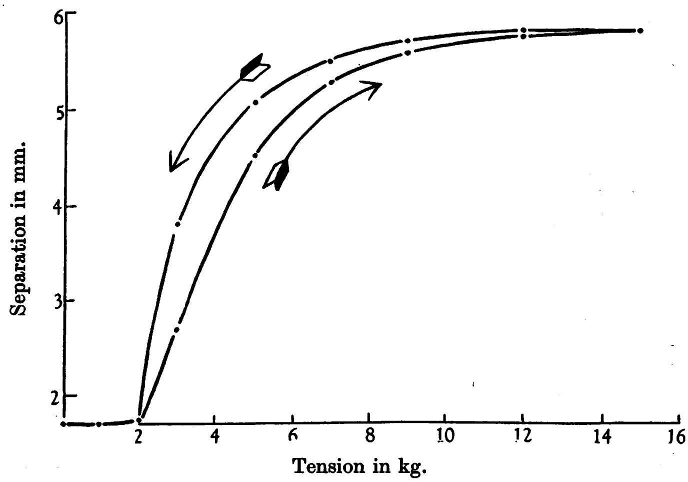
JOINTS WHICH DO NOT CRACK

The commonest cause of failure to produce a crack in the metacarpo-phalangeal joint is inability to relax the muscles whose tendons pass across the joint. But some individuals show a minimal separation of the bones at extreme tensions and inability to crack, though the tendons appear slack on palpation (Text-fig. 3). Possibly this is due to shortness of the collateral ligaments which would prevent a separation sufficient to produce a crack, for even prolonged pulls fail to separate the bones in these subjects to an extent comparable to that usually found.

In other subjects the bones separate easily under relatively light tension without cracking and without the appearance of a space. In such subjects remarkable degrees of hyperflexion and hyperextension are found, and the capsules and ligaments appear to be exceptionally lax, so that it is impossible to obtain the degree of tension in the synovial fluid required for cracking. In most subjects, in whom the metacarpo-phalangeal joint of the third digit cracks easily on direct tension, the corresponding joint of the fifth belongs to the lax class, and seldom cracks in response to direct traction.



Text-fig. 3. Record of the separation of the bones in a joint which did not crack (R. W. H.).



Text-fig. 4. Record of the separation of the bones in a joint which showed a space but did not crack (C. B. B. D.).

Another type shows wide separation and the presence of a space at relatively low tensions (4·5 mm. at 5 kg., Text-fig. 4 and Pl. 1, fig. 8). The course of the graph follows an even S-shaped curve from minimal to maximal tension, and the outward and returning tracks are close to each other. The behaviour of such joints is similar to that of other joints in their refractory phase and a space can always be demonstrated if the bones are sufficiently separated.

A joint, then, may fail to crack owing to either an inability to form a space at all or the too facile appearance of the space, so that the bones move apart smoothly instead of springing apart suddenly.

SUMMARY

1. In the resting phase the articular surfaces of the joint are in contact.

2. Light tension, up to about 6 kg., insufficient to produce cracking, leads to the phase of preliminary separation of the articular surfaces; recompression leads to reapposition of the surfaces with a sharp knocking sensation.

3. Stronger tensions, of about 7 kg. or more, lead to cracking. The noise is heard, the bones spring sharply apart, a groove appears in the skin over the joint, and a clear space appears in the radiograph within the synovial cavity.

4. The space is interpreted as a partial vacuum occupied by water vapour and blood gases under reduced pressure.

5. Measurement of tension indicates that the joint fluid sustains an absolute negative pressure of about $2\frac{1}{2}$ atm. before cracking occurs. As the space develops the pressure presumably rises to the vapour pressure of water.

6. After cracking, the joint is in a refractory phase and no further cracking can be elicited by direct tension for about 20 min. This phase is probably dependent upon the presence of a small gas nucleus in the fluid.

7. Inability to crack may be due to an inability to reduce pressure sufficiently in the joint cavity, or to the appearance of a space within the fluid at too low a tension.

Our thanks are due to Prof. A. B. Appleton, Drs J. F. Brailsford, J. Cyriax and J. W. McLaren for advice and assistance, and to our colleagues who have acted as subjects. Expenses were met by a grant from the Central Research Fund of the University of London.

REFERENCES

Christen, T. (1911). Richtigstellung zum Streit um den Gelenkdruck. *Anat. Hefte*, **43**, 414*a*–414*b*.

Dean, R. B. (1944). The formation of bubbles. *J. appl. Phys.* **15**, 446–451.

Dixon, H. H. (1938). Transport of substances in plants. *Proc. Roy. Soc.* B, **125**, 1–25.

Dittmar, O. (1932*a*). Der Kniegelenks-Meniskus im Röntgenbilde. *Röntgenpraxis*, **4**, 442–445.

Dittmar, O. (1932*b*). Zur Röntgenologie des Kniegelenkes. *Verh. dtsch. orthop. Ges.* **27**, 225–256.

Felsenreich, F. (1935). Darstellung des verletzten Meniscus medialis im Röntgenbild bei veralteter Kreuzband- und Seitenbandverletzung. *Röntgenpraxis*, **7**, 331–333.

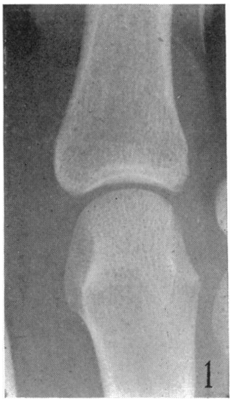
Fick, R. (1911). Zum Streit um den Gelenkdruck. *Anat. Hefte*, **43**, 397–414.

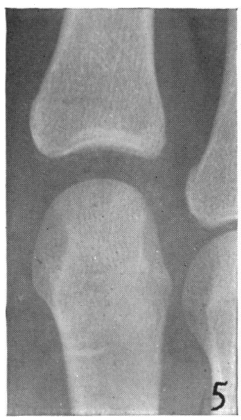
Harvey, E. N., Barnes, D. K., McElroy, W. D., Whitely, D. C. P. & Cooper, K. W. (1944). Bubble formation in animals. I. Physical factors. *J. cell. comp. Physiol.* **24**, 1–22.

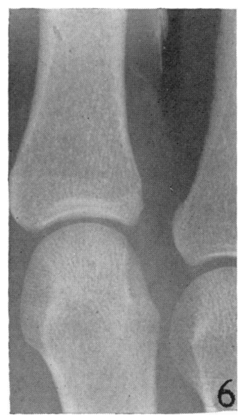
Harvey, E. N., Whitely, A. H., McElroy W. D., Pease, D. C. & Barnes, D. K. (1944). Bubble formation in animals. II. Gas nuclei and their distribution in blood and tissues. *J. cell. comp. Physiol.* **24**, 23–34.

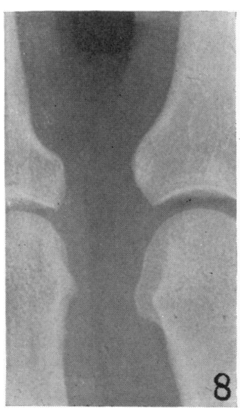
Mennell, J. (1939). *The Science and Art of Joint Manipulation*, **1**. London: Churchill.

Nordheim, Y. (1938). Eine neue Methode, den Gelenkknorpel, besonders die Kniegelenkmenisken, röntgenologisch darzustellen (ohne Zuhilfenahme eingespritzten Kontrastmittels). *Fortschr. Röntgenstr.* **57**, 479–495.









ROSTON AND WHEELER HAINES—CRACKING IN THE METACARPO-PHALANGEAL JOINT

EXPLANATION OF PLATE

Fig. 1. Resting metacarpo-phalangeal joint of medius (J. B. R.).
Fig. 2. At 7 kg. tension, before cracking, showing slight separation of the bones (J. B. R.).
Fig. 3. At 9 kg. tension, after cracking, showing the appearance of a space (J. B. R.).
Fig. 4. At 18½ kg. tension, after cracking, showing the space enlarged (J. B. R.).
Fig. 5. At 5 kg. tension, after cracking, showing the space still visible at low tension (J. B. R.).
Fig. 6. Resting after cracking. No space visible in the resting joint (J. B. R.).
Fig. 7. At 9 kg. tension, after cracking, showing multiple bubbles (R. H. S. W.).
Fig. 8. At 3 kg. tension, showing space formed without cracking (C. B. B. D.).
Fig. 9. Effect of prolonged pull; separation without cracking or formation of a space (J. B. R.).